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COMPARISON OF CINEMATOGRAPHY
AND FORCE-TIME CURVES IN
A SPRINT START

by



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A THESIS

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The undersigned certify that they have read,
and recommend to the Faculty of Graduate Studies and
Research for acceptance, a thesis entitled "Comparison
of Cinematography and Force-Time Curves in a Sprint Start,"
submitted by Eric John Charles Sprigings in partial
fulfilment of the requirements for the degree of Master of
Science.

ABSTRACT

The purpose of the study was to explore the interrelationship between film analyses and force-time recordings of a particular event (the sprint start). Also, an attempt was made to determine the amount of the total impulse which each segment contributes throughout the start.

Two volunteer male subjects were used. One was a good highschool sprinter and the other was a University of Alberta student who had very little experience in track sprint starting. They were each instructed to perform five sprint starts from the starting blocks.

From the resulting force-time graphs and film analyses the following information was obtained:

(1) horizontal movement time; (2) synchronization of body positions with force-time curves; (3) position of total maximum force, as well as position of maximum force recorded by left and right legs; (4) total horizontal impulse and its breakdown into the impulse received by each segment; (5) horizontal velocity of the sprinter; (6) a means for establishing more accurate boundaries when attempting to measure the area under a force-time curve.

In view of the results, it was concluded that a force recording instrument which was statically calibrated could be

used in predicting values and pattern of movement obtained by cinematographical analysis. No conclusions could be made on the magnitude of the impulse which a particular segment generates during a sprint start.

ACKNOWLEDGEMENT

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

In the last few decades a limited quantity of published research has been reported to determine the magnitude and duration of the force which the sprinter imparts to the starting blocks during the start. In the early stages of this research, the primary interest was to determine the maximum force exerted by each foot for varying starting techniques as well as the total impulse for the various starts.

In 1952, Henry (1952) published his study on the theoretical implications that the physical quantity called impulse had upon a sprinter's true velocity from the blocks.

...a more forceful start must necessarily, on straight-forward physical grounds, impart a great [sic] velocity to the runner's body mass. Even though the greater velocity is secured at the expense of an initial time loss, it should result in a faster run although the sprinter with the quicker but weaker start may lead for a few yards.

Henry's reasoning was that since the horizontal change in velocity of the sprinter's center of gravity is directly proportional to the horizontal impulse, it therefore becomes evident that the longer the sprinter can apply an optimum force to the blocks, the greater will be the increase in horizontal velocity of the sprinter's center of gravity.

The horizontal impulse was therefore the true measure of the sprinter's speed at the start of a race.

Howell (1956) saw the practical implications of studying the force-time curves of sprint starting, and in his sprint coaching he encouraged one group of subjects to try and move out of the blocks in such a fashion as to increase the area, and hence the impulse, under their recorded force-time curves. The results of this technique of coaching in the sprint start appeared to be superior to just verbal instruction and demonstration.

This method of teaching, although good, requires a trial and error method approach to producing a greater impulse. If however, the area under the force-time curve could be broken down into the impulse exerted by each major body segment during various stages of the start, the instructor would be able to compare the segmented areas of the force-time curve of a novice to that of a sprinter with a good start and then be able to instruct the novice on how he should be concentrating on applying more in terms of magnitude and/or period of time to a certain segment(s) during the start.

No studies are found in the literature which attempted this break-down of the total horizontal impulse of a sprint start into its segmental components.

The Problem

The purpose of this study is to assess the contribution of each major body segment to a sprint start, and to compare the results of a cinematographical analysis with the results from the force-blocks.

Delimitations

The delimitations of the study were as follows:

1. The study was delimited to two subjects of average build.

Definition of Terms

Sprint Start

In this study a sprint start refers to a start used in a short distance running event. The start commences with the firing of the starting gun and is terminated the moment that the subject's back foot touches the ground in front of the starting line. It is realized that in the practical situation the sprint start is only a small part of the whole race. However the differences in the abilities of sprinters are very often measured in hundredths of seconds and hence a minor contribution becomes one of major importance

CHAPTER II

REVIEW OF LITERATURE

Force-Time Measurements of the Sprint Start

Henry (1952) published his research results on the impulse characteristics of the sprint start. He obtained his force-time recordings by means of a mechanical link-up from both foot-blocks to a moving chronograph tape. An event marker was also connected so as to record the time of the starting signal. From these force-time recordings, Henry was able to calculate the sprinter's center of gravity velocity at the time his front foot left the blocks. He concluded that the greater the total horizontal impulse was for a given block spacing, the better would be the sprinter's start. From this, he [1952:317] stated that the ideal start would be one in which there is "... early development and maintenance of full maximal thrust with each leg until the respective blocks are cleared as a necessary result of forward motion."

Howell (1956) used the force time recordings as a teaching aid to novice sprinters. He reported that the group which was shown their respective force time curves after each start and encouraged to try and duplicate the shape of Henry's 'ideal start', showed a significant improvement over the control group which did not receive the benefit of seeing

their force-time recordings.

Lanier (1968) using force-blocks equipped with DCDT (direct current differential transformer) displacement transducers, and one sprinter, reported [1968:44] that "despite the fact that the back foot exerts a greater maximum force in the start, the front foot contributes twice the impulse to the final block velocity as does the back foot." He also reported that for his subject the greatest force was applied by the back leg and that this force was about thirty percent greater than the maximum force of the front leg.

Comparison of Results of Force-Time Recordings and Cinematography

Murray, Seireg, and Scholz (1967) used both film analysis and a force recording platform to determine the impulse which a subject exerted against his center of gravity during nine simple movements such as squatting and standing up again. Murray [1967:836] reported that "for all nine of the activities tested, the patterns of the calculated vertical supportive forces closely approximated the measured force patterns although the magnitudes were not always equal." He attributed these small differences in magnitude, which tended to occur at the times of the peaks and valleys in the force patterns, to the process of differentiation used to obtain the accelerations in the film analysis, and to the approximation of the center of gravity for the body segments.

Russel (1967) combined cinematography with the analyses of the force-time curves in order to determine the take-off velocity for a swimming sprint start. He reported a poor relationship between the force-time recordings and those calculated from the film analysis.

Lanier (1968) compared the use of force-blocks and cinematography in the measurement of horizontal velocity of a sprinter in a track sprint start. He suggested that the relative error in determining the horizontal velocity was approximately twice as great for the cinematographical method as for the force-time recordings. An attempt was made to evaluate the information produced by the force-blocks.

Payne, Slater, and Telford (1968) combined the use of the force platform and cinematography in the skill analysis of seven different athletic events. The impulse recordings exerted by the feet were obtained and related to the body movements shown on the film. They concluded with the suggestion that further research was needed in order to measure the mechanical principles of an activity more specifically than they had been able to do.

Sinclair (1970) used force-time recordings and film analysis in order to compare the movement times, reaction times, and the horizontal velocities for the swimming sprint start as measured by these two separate techniques. She claimed to have determined the body position(s) for maximum horizontal force and for zero horizontal force.

In 1971, Roy, as cited by Roberts (1971), used a force platform and cinematography in order to analyse the take-off phase of the standing long jump for boys seven to sixteen years of age. He placed markings on the subjects' segments centers of gravity in order to be able to study kinetics of individual body segments as well as of the total body. Roy found that the measurements of vertical force as measured by these two techniques were in close agreement and that the maximum deviation was about nine percent. Thus, as was concluded by Roberts, it is reasonable to assume that the data on the individual body segments, as measured by film analysis, are reasonably accurate and it is this breakdown into individual segment motion which gives the insight into the biomechanics of motor skill.

Payne and Blader (1971) used cinematography and force-time recordings to measure the magnitudes as well as the angles and points of applications of the resultant forces for both feet at any instant during the start. Payne found that in general both front and rear legs started to exert forces upon the blocks at the same time but that it was the front foot which recorded the greater portion of the body's total horizontal impulse. Payne describes the shape of the rear foot trace as being symmetrical while that of the front foot tended to show two peaks with the second higher than the first.

Proportional Weights of Body Segments

In 1860 Harless, as cited by Woods (1967), dismembered two young adult cadavers and measured the weights, lengths and the position of the center of gravity of various body segments. His results were probably lacking in accuracy due to the fact that they were beheaded criminals and thus a great deal of blood was lost before he actually weighed the segments. Also, his lines of dissection were not well chosen and thus did not approximate the natural segment lengths which one would normally think of when working with cinematography.

In 1898, Braune and Fischer, as cited by Williams and Lissner (1962), refined the dismembering techniques and performed measurements on three frozen male cadavers. There measurements have proven to be good but of course their sample population was very small.

In 1936, Bernstein, as cited by Drillis (1964), carried out an extensive investigation on body segment parameters of seventy-six living male subjects and seventy-six living female subjects. By using the volume and density technique, Bernstein estimated the segment masses for his subjects. When the segment values are compared with the percent of total body weight as established by Braune and Fischer, they are all found to be of lower magnitude.

No further significant contributions in this area of research were made until 1955, when Dempster, as cited in Williams and Lissner (1962), published his study based on

eight male cadavers of approximately medium build. This larger sample population should give better approximations to the percent body weight of each segment.

Hanavan (1964), using the regression equations developed by Barter to determine segment weights, did a study on sixty-six subjects. He set up a table which would allow for variation in percent segment weight with a change in total body weight. Although basically a good idea and an improvement on Dempster's work, it can not be assumed that this data can be carried over to any subject of differing somatotype.

CHAPTER III

METHODS AND PROCEDURES

Apparatus

In order to measure the change in momentum relative to the ground for each major segment of the body during the start, film analysis was used.

Camera. A 16 mm Beaulieu camera was used to film the start. A split lens was used in order to allow focusing on both the subject, and the chronoscope which was placed in the upper left hand corner of the picture frame. Kodak Ektachrome colour film (125 ASA) was used and the filming speed was set for approximately sixty-four frames per second.

Timing device. A chronoscope, which was accurate to one hundredth of a second, was filmed during the start by using a split lens on the camera. This allowed accurate calculation of the filming speed during the time of the start.

Starting gun. A regular double action .22 caliber starting pistol was electrically equipped with a micro switch which opened when the hammer of a gun came down on the cartridge during the firing of the gun. An electrical connection was made to the chronoscope and interval timing device.

Interval timing device. Two interval timing devices were connected together to form a recycling unit which was used to activate the event markers on the Beckman and Honeywell recorders every .27 seconds. It also activated every .27 seconds a light bulb which could be viewed in the upper left hand corner of each frame of film.

Reference board. An eight foot by four foot section of plywood, which was marked off in six inch squares, was filmed after the subject had been tested. The plywood section was placed at the same distance from the camera as the center bar of the starting blocks and this gave a reference for assessing the actual distance that the subject moved per frame of film.

Cinematography. The camera was set on a tripod so that the lens was at a height of four feet and at a distance of twenty-one feet from the side of the starting blocks. The camera was locked on line with a point located two feet ahead of the starting blocks. The chronoscope was placed 1 1/2 feet from the camera in the upper left hand corner of the picture frame. The light bulb was also placed in the upper left hand corner of the picture frame. The sprinter was positioned so as to run from left to right in the filming. The camera was started when the command 'set' was given and stopped when the subject was two steps out of the blocks. The reference board was filmed immediately after testing the subjects.

In order to record the total positive horizontal effort exerted through each foot against the starting blocks, special force blocks were used.

Force-blocks. The force-blocks are sprint starting blocks which use a Sanborn 7, DCDT displacement transducer to measure the effort exerted against the foot-blocks in the horizontal direction. The damping and restoring force of the blocks is supplied by the torque from a half inch torsion bar.

DCDT transducer. The working principle behind a DCDT (direct current differential transformer) transducer is as follows: The line a.c. voltage (60 Hz) is converted to a desirable d.c. signal (6 volts) by passing it through a rectifier, filter and a voltage divider. The d.c. signal is then passed through an oscillator which produces a set carrier frequency of nine KHz. This oscillating signal activates the primary coil which sets up an oscillating magnetic field which in turn induces a voltage in the secondary coil. A soft iron core (magnetically soft) can be moved in between the two coils which will set up a stronger magnetic field of its own. This increases the intensity of the magnetic field at the secondary coil and thus produces a greater voltage at this coil. The position of this core is the determining factor as to what the induced voltage at the secondary coil will be. The transducer used has been designed to give a linear voltage response ($\pm 0.5\%$ within a range of 2.8V) to the

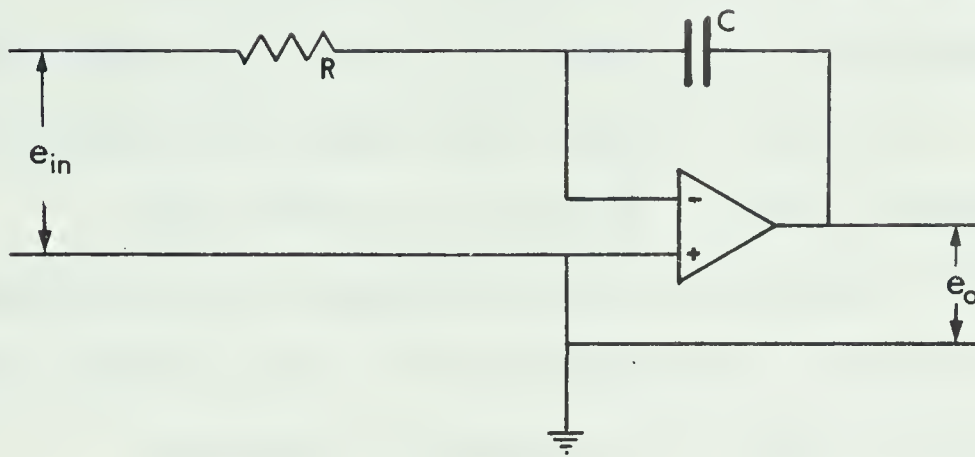
displacement of the core which is proportional to the applied force. The oscillating voltage produced at the secondary coil is then passed through a demodulator, which removes the signal from the carrier frequency so that a d.c. output voltage is obtained. This d.c. voltage is then passed through the preamplifier of both the Beckman RS Dynograph and the Honeywell Physiological Unit, where the desired deflection (sensitivity volts/cm) of the pen or light beam of the recorders can be set.

Integrator. The Honeywell Physiological Integrator was used to measure the combined area under the force-time curve (i.e. impulse) at any time during the start. A basic integration circuit is schematically shown in Figure 1.

O.A. adder. In order to sum the two voltages from the transducers, an operational amplifier adder was constructed. The circuit is schematically shown in Figure 2.

Subjects

Two volunteer male subjects were used in the experiment. One of the subjects was an experienced sprinter from the Edmonton Olympic track team, and the other was a student from the University of Alberta who had very little experience in starting from blocks.



Where: Q = charge on capacitor
 C = capacitance

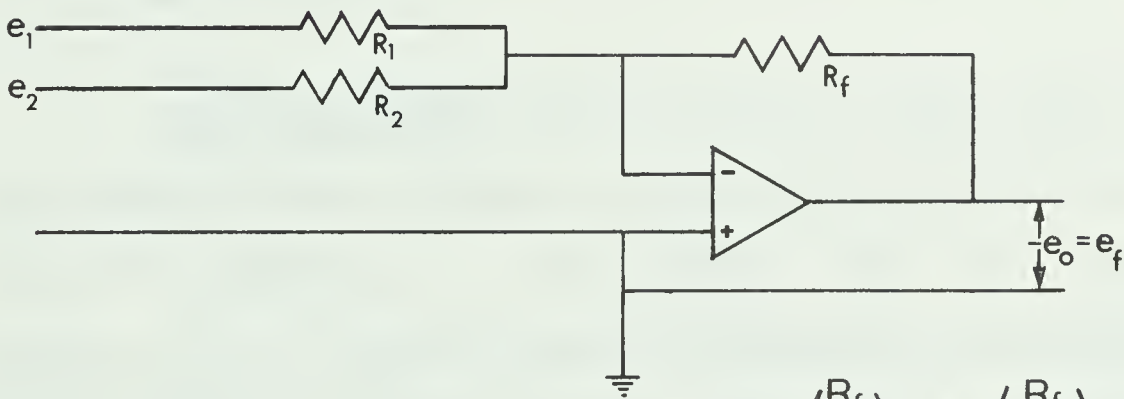
Voltage across capacitor = $V_c = \frac{Q}{C}$

$$Q = -\int i_{in} dt$$

FIG. 1: OPERATIONAL AMPLIFIER INTEGRATOR

$$V_c = e_o = -\frac{1}{C} \int i_{in} dt$$

$$i_{in} = \frac{e_{in}}{R} \quad e_o = -\frac{1}{RC} \int e_{in} dt$$



$$e_f = e_1 \left(\frac{R_f}{R_1} \right) + e_2 \left(\frac{R_f}{R_2} \right)$$

$$\text{If } R_f = R_1 = R_2 \text{ then } e_o = -(e_1 + e_2)$$

FIG. 2: OPERATIONAL AMPLIFIER ADDER

The following parameters were measured and recorded in Appendix A: Age; Height; Weight; Segment Center of Gravities; Segment Lengths; and Segment Weights.

The subjects' segment lengths were measured in accordance with the link boundaries established by Dempster, as cited by Williams and Lissner (1962:133).

The centers of gravity of these segments (or combination of segments) were established through Dempster's data and the use of the 'principle of moments' (See Appendix A).

In order to determine the mass of each of the major segments of the two subjects, the reaction board technique outlined by Drillis, Contini, and Bluestein (1964) was used.

Weighing scale. A Health-O-Meter weighing scale with a maximum capacity of 350 pounds was used to measure the reaction force of a board with a subject lying at rest on it in various positions.

Reaction board. The reaction board (see Figure 3) was made of wood and had the following dimensions: length - 78 1/4"; thickness - 1 1/2"; width - 18". Two eighteen inch pieces of 3/4 inch pipe were fastened to the board so that their longitudinal axes were 1 inch and 3 1/4 inches respectively from the ends of the board. Thus the distance between the two supports was exactly seventy-four inches. A vertical foot support was attached to that end of the board which had the pipe's longitudinal axis located one inch from the end.

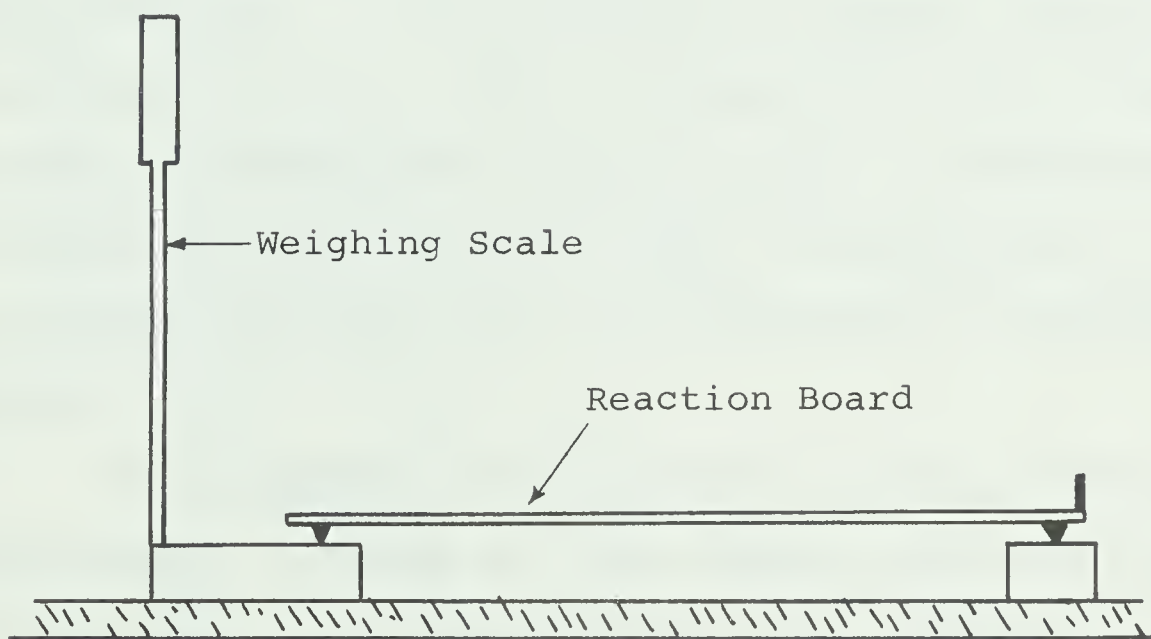


FIG. 3: APPARATUS FOR MEASURING THE MASS OF
BODY SEGMENTS

Limb positioner. A goniometer and a protractor were used to set the subject's segment to a position of ninety degrees with respect to the horizontal or vertical.

The subject, dressed only in a bathing suit and gymnastic slippers, was instructed to lie down on his back with the soles of his feet pressed against the foot board. The reaction force of the subject was then recorded in the positions shown in Appendix A. The limbs were positioned to an angle of ninety degrees with the aid of a goniometer and protractor. The goniometer was not attached to the subject as it would alter the segment's mass.

Testing Procedures

The following experimental work was conducted in a large laboratory in the University of Alberta Physical Education Building in order to control the environmental variables of weather and light, as well as provide access to electrical power outlets. Also, it assured the experimenter that the start was performed on a horizontal surface.

The equipment was calibrated (see Appendix B) and positioned as in Figure 4. The outputs from both transducers were fed into the Beckman recorder's two channels in order to give a separate pen recording for each foot. The same outputs from the transducers were also connected to an operational amplifier adder and fed into the integrator system of the Honeywell, as well as the 113 Accudata Bridge Amplifier

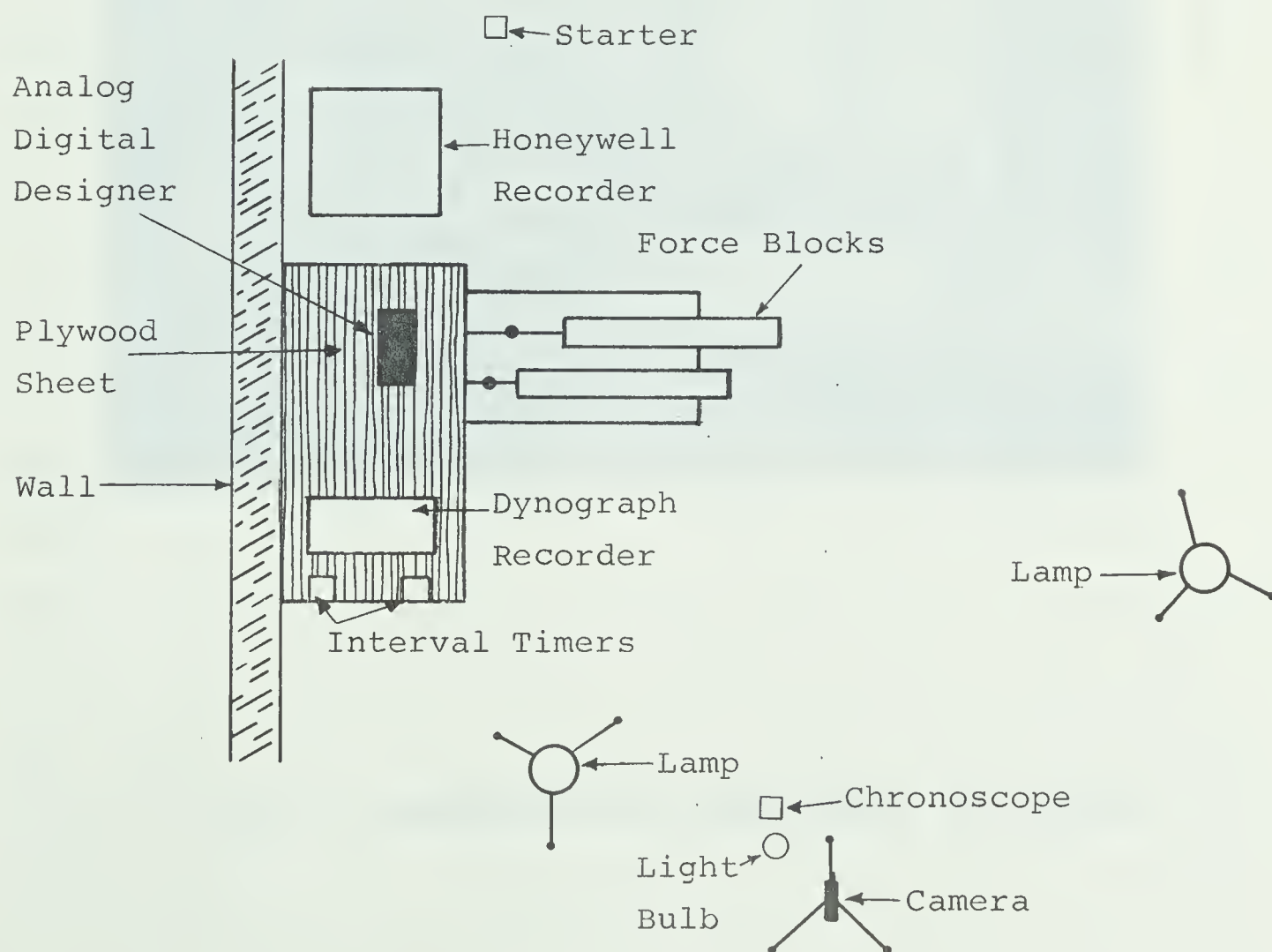


FIG. 4: SCHEMATIC DIAGRAM OF OPERATIONAL SETUP

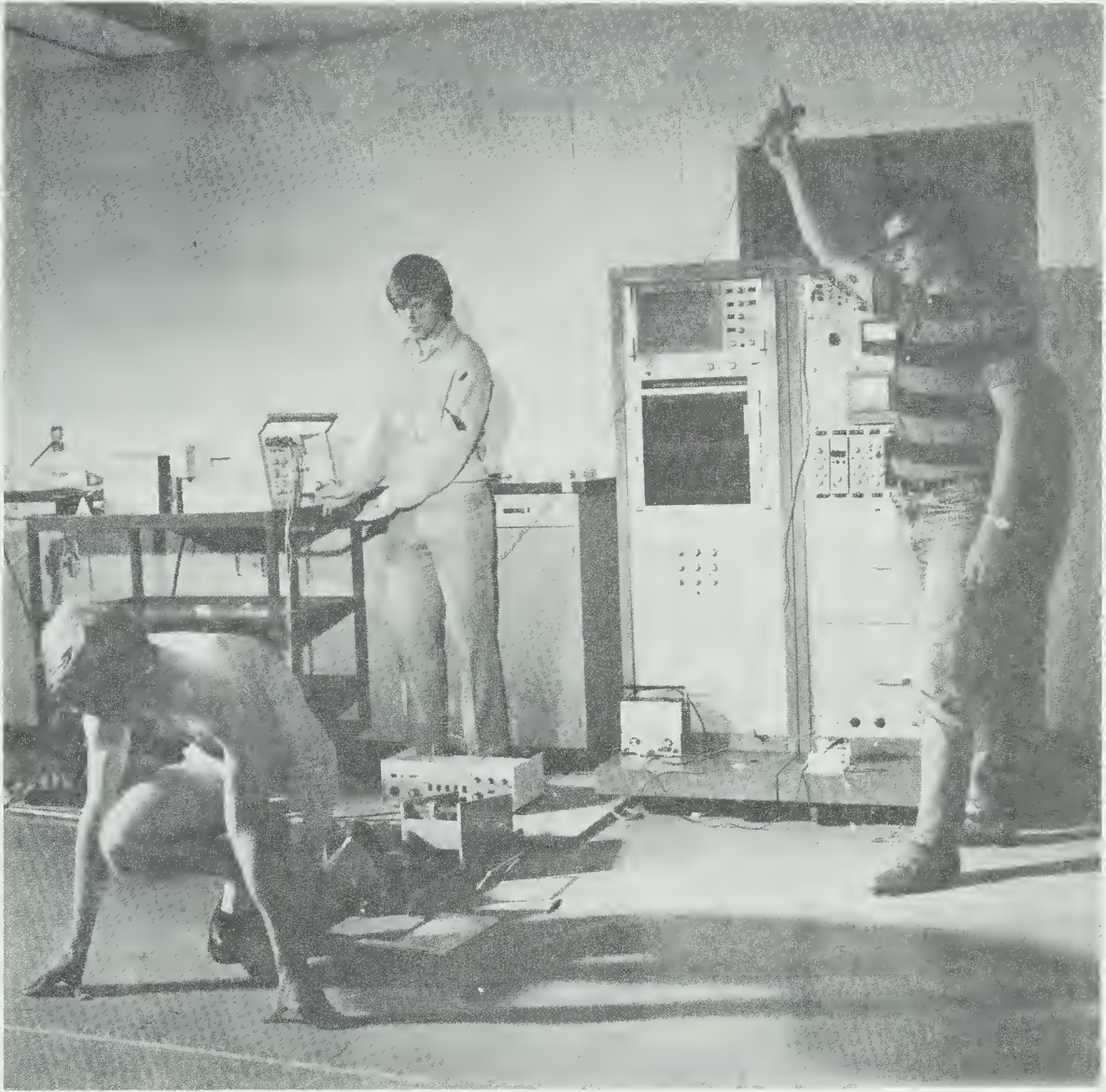


FIG. 5. APPARATUS FOR MEASUREMENT OF IMPULSE

(d.c.) of the Honeywell. The output from both the integrator and d.c. preamplifier (i.e. 113 Accudata Bridge Amplifier) were recorded on two channels of the Honeywell recorder.

Connections were made from the starting gun to the chronoscope and interval timer which in turn was connected to the light bulb and the event markers of both the Beckman and Honeywell recorders.

The two subjects were dressed in swimming trunks only. The subjects wore gymnastic slippers in order to facilitate the measurement of the foot in the film analysis.

Red crosses, made from adhesive tape, were placed on the boundary links of each of the main body segments of the subjects. The crosses were placed such that they could be viewed as the subject ran from left to right.

The experienced subject was allowed a number of practice starts (transducers disconnected) so as to get used to his preferred spacing of the blocks. The inexperienced starter was allowed three trial starts from the block spacing used by the experienced sprinter. Each subject was then tested on his start five times. The subjects alternated each time so as to reduce fatigue. The starter's command was as follows: "on your marks" - "set" - firing of gun. On the command "set", the camera and recording instruments were turned on. The systems were shut down after the sprinter had taken two steps out of the blocks. At the end of the trials for both subjects, the reference board was filmed under the specifications previously mentioned.

CHAPTER IV

RESULTS AND DISCUSSION

Results

The two subjects, after warm-up, performed five starts each with no false starts being detected. The fourth start of both subjects was chosen to be studied because of the similarity of pattern of their respective force-time recordings.

A link-up between each frame of film and its corresponding position on the force-time curve was obtained. The synchronization of particular frames with their corresponding positions on the combined and individual force-time curves is given in Table I and illustrated in Figure 6 and Figure 7.

Comparison of Results of Film Analyses and Force-Time Recordings

Impulse. A computer program, developed by Miller (1970), was used to aid in the calculating of the positions of the center of gravity for each body segment throughout the start. With the position of the center of gravity having been determined, it was then possible to calculate the size of the impulse given to each of the body's segments during

TABLE I

Interrelationship Between Cinematography
and Force Recordings

Experienced Starter (See Fig. 5)			
Description	Frame #	Letter on Graph	Time elapsed from signal (sec.)
Initiation of Horizontal Force	#7	A	.12
Maximum force of back leg; Maximum horizontal acceleration of total body's center of gravity; Both hands leave the ground.	#14	B	.23
Back foot leaves block.	#19	C	.32
Maximum force of front leg.	#25	D	.42
Termination of impulse on the blocks.	#27	E	.46
Front foot has left the blocks.	#29	F	.49

TABLE I (Continued)

Inexperienced Starter (See Fig. 6)			
Description	Frame #	Letter on Graph	Time elapsed from signal (sec.)
Initiation of Horizontal Force	#8	A	.14
Maximum force of back leg; Maximum horizontal acceleration of total body's center of gravity; Both hands leave the ground.	#13	B	.23
Back foot leaves block.	#21	C	.37
Maximum force of front leg.	#26	D	.46
Termination of impulse on the blocks.	#28	E	.50
Front foot has left the blocks.	#30	F	.52

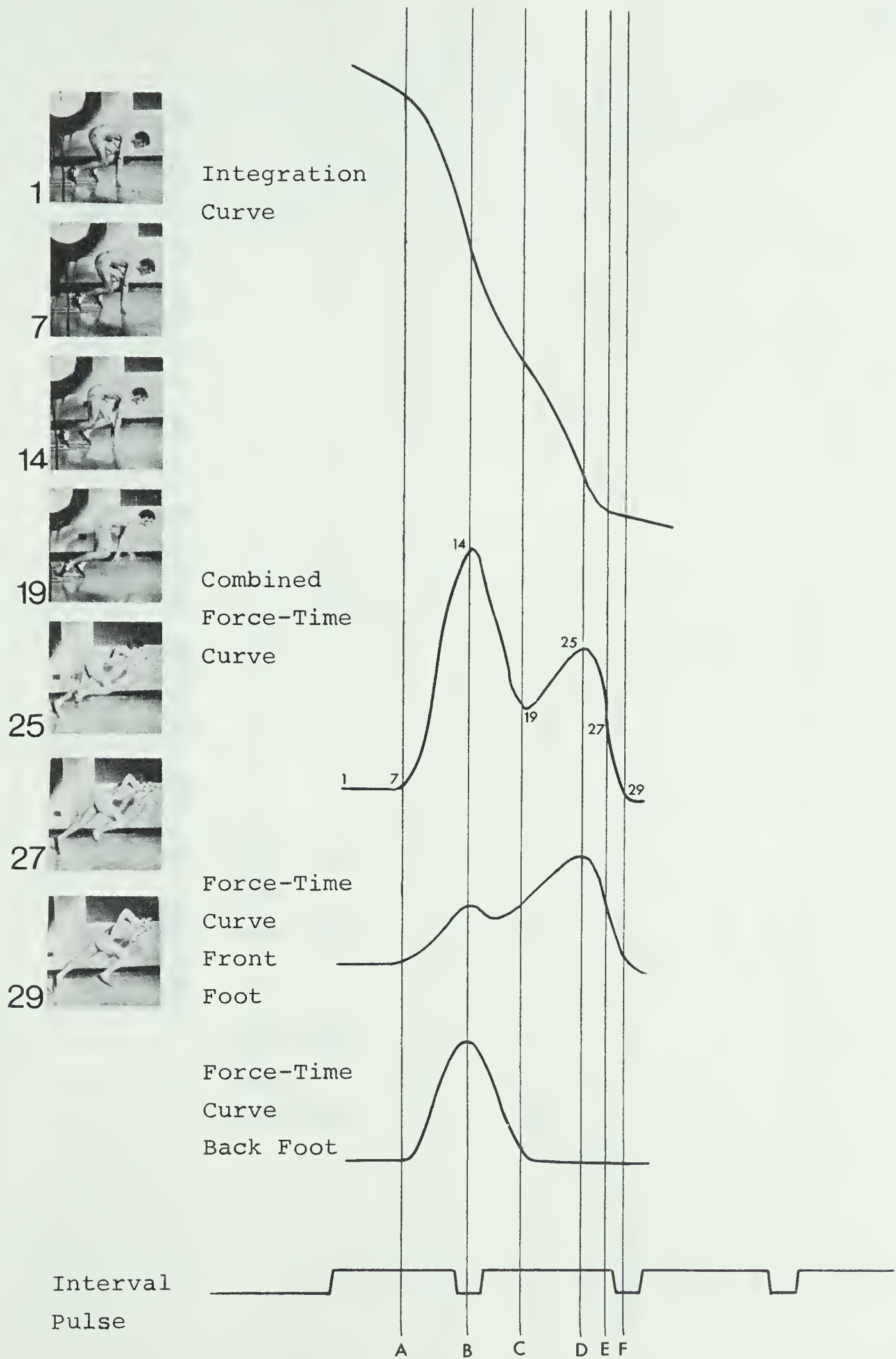


FIG. 6: SYNCHRONIZATION OF BODY POSITIONS WITH FORCE-TIME CURVES (EXPERIENCED SPRINTER)

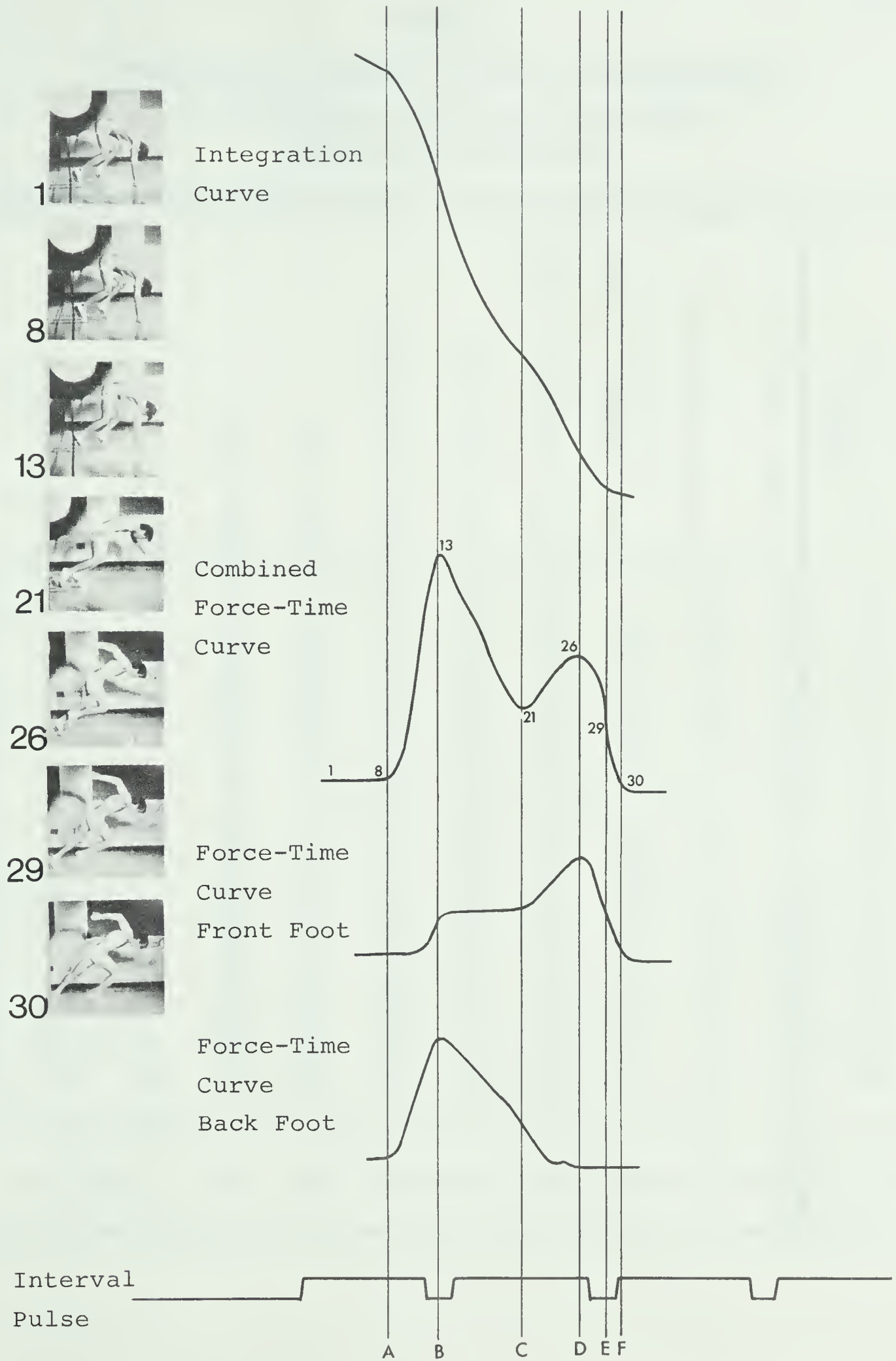


FIG. 7. SYNCHRONIZATION OF BODY POSITIONS WITH
FORCE-TIME CURVES (INEXPERIENCED SPRINTER)

TABLE II

Comparison of Impulse (Lb.Sec) Determined by
Film Analysis and Force Recordings
(Experienced Sprinter)

Frame Interval	Head and Neck	Trunk	Right Arm	Left Arm	Right Upper Arm	Left Upper Arm	Right Forearm & Hand	Left Forearm & Hand	R-Lower Leg & Foot	L-Lower Leg & Foot	Total (Film Analysis)	Total (Honeywell Integrator)
7.5 → 8.5	.24	.40	0	0	-.40	.04	-.07	0	-.76	.18	-.37	0
8.5 → 9.5	0	.40	0	0	-.36	.04	.13	0	-.26	.12	.07	.85
9.5 → 10.5	.94	3.6	.19	.25	.55	.47	.12	.12	.29	-.20	6.40	2.3
10.5 → 11.5	.24	.82	.10	-.10	.22	-.40	.25	-.12	.20	.10	1.30	3.5
11.5 → 12.5	.24	3.4	.09	.09	.73	.73	.01	0	.26	-.02	5.50	4.0
12.5 → 13.5	0	-3.6	.08	-.41	.51	.22	.31	.38	.28	.09	-2.20	5.6
13.5 → 14.5	.47	6.5	-.01	.58	.87	.73	-.13	.12	.64	-.18	9.60	6.0
14.5 → 15.5	.47	3.2	.15	.09	.58	.40	.07	.26	.0	-.02	5.20	4.4
15.5 → 16.5	.47	1.7	0	.07	1.5	.40	.03	1.1	1.2	.02	6.50	2.5
16.5 → 17.5	-.47	.82	.08	.22	.07	-.18	.01	-.20	.45	0	.80	1.7
17.5 → 18.5	0	-2.2	-.11	-.19	1.1	.25	.12	.91	.61	0	.53	1.7
18.5 → 19.5	-.23	4.0	.07	.62	.65	.18	.08	.94	1.0	0	7.40	1.4
19.5 → 20.5	-.24	2.3	.28	-.15	1.1	.22	.51	.05	.83	.11	5.00	2.0
20.5 → 21.5	.71	-1.8	-.12	.04	.18	-.34	.07	-.32	.57	.08	-.90	2.2
21.5 → 22.5	-.24	1.2	.04	.07	.37	-.07	.48	-.36	.36	-.06	1.80	2.6
22.5 → 23.5	.71	-1.2	.10	.11	-.62	-.32	.02	.26	.45	-.03	-.54	2.7
23.5 → 24.5	0	0	.13	-.12	.22	.07	-.16	-.54	.39	.44	.44	2.7
24.5 → 25.5	.23	5.1	-.16	-.02	.44	1.2	-.11	-.43	-.09	.02	6.20	2.6
25.5 → 26.5	.94	-1.8	.16	-.45	.55	-.40	-.17	-.74	0	-.16	-2.00	1.3
26.5 → 27.5	.24	.12	-.22	-.02	-.84	.76	-.31	-.29	-.36	1.4	.47	.22
Total Impulse	4.72	23.6	.86	.68	7.46	4.00	1.25	1.09	6.03	1.88	51.15	50.05

TABLE III

Comparison of Impulse (Lb.Sec) Determined by
Film Analysis and Force Recordings
(Inexperienced Sprinter)

Frame Interval	Head and Neck	Trunk	Right Arm	Left Arm	Right Upper Arm	Left Upper Arm	Right Forearm & Hand	Left Forearm & Hand	R-Lower Leg & Foot	L-Lower Leg & Foot	Total (Film Analysis)	Total (Honeywell Integrator)
7.5→ 8.5	0	-.59	-.04	-.04	-.49	0	0	0	-.44	0	-1.61	0
8.5→ 9.5	.13	.13	.02	.04	.38	.23	-.08	.17	.08	-.09	1.01	1.8
9.5→10.5	1.0	-.88	-.17	-.08	.57	-.19	-.63	.07	-.18	0	-.48	2.8
10.5→11.5	.63	3.4	.18	.23	-.68	.42	.31	.05	.27	.07	4.83	4.1
11.5→12.5	.25	2.2	.18	.28	.56	.19	.19	-.11	.50	.28	4.49	4.1
12.5→13.5	.51	4.6	.13	.09	.83	1.1	-.51	.22	.28	-.19	7.13	4.4
13.5→14.5	0	-1.2	-.15	.23	.38	-.11	-.24	.41	0	.01	-.63	4.2
14.5→15.5	0	4.4	-.03	.39	.19	.52	.05	.32	.17	.07	6.04	3.6
15.5→16.5	.76	-1.2	.09	0	-.15	.04	.07	.39	.10	.09	.23	3.2
16.5→17.5	.25	3.2	.15	.07	1.5	.46	-.01	.17	.41	.01	6.18	2.2
17.5→18.5	-.51	-1.6	-.01	.16	.15	-.64	.42	.75	.75	-.01	-.54	1.8
18.5→19.5	.76	.44	.16	-.04	1.1	.42	-.37	.05	.59	-.16	2.94	1.6
19.5→20.5	-1.0	2.8	.08	.26	.76	.26	.31	.58	.60	.09	4.69	1.4
20.5→21.5	.51	-2.2	-.07	-.12	.26	-.34	.37	-.07	.53	-.09	-1.21	1.3
21.5→22.5	-.76	2.9	.48	.09	.79	.87	.95	.11	.59	.25	6.28	1.5
22.5→23.5	.50	.72	.04	.10	1.6	1.0	.51	.56	1.0	.26	6.31	2.0
23.5→24.5	-.25	2.3	.02	-.08	-.15	-.87	.57	-.28	-.01	-.25	1.02	2.2
24.5→25.5	.25	2.5	.16	.05	-.45	.41	.35	-.82	.08	0	2.50	2.3
25.5→26.5	0	-.88	.03	.15	.30	-.22	-.23	.06	.58	.10	-.17	3.0
26.5→27.5	.25	1.8	.23	-.03	-.19	.19	-.17	-.41	-.10	.09	1.61	1.6
27.5→28.5	.25	-.59	-.35	-.50	.38	.34	.71	-.94	.42	.62	.34	.90
Total Impulse	3.53	22.17	1.07	1.25	7.59	4.13	2.57	1.28	6.23	1.15	50.96	50.00

specific periods of the start (Appendix C). The total impulse, which the body received over the time period indicated between frames of consecutive exposure, was compared to the impulse the body received as recorded by the Honeywell Integrator (Table II, Table III).

Velocity. The final velocity of both sprinters, just after leaving the blocks, was calculated (Table IV).

TABLE IV

Final Velocity Just After Leaving
the Starting Blocks

	Film Analysis (ft/sec)	Force Recording (ft/sec)
Experienced Sprinter	10.98	11.19
Inexperienced Sprinter	10.27	10.25

Force-Time Analyses

Impulse. The impulse recorded from the front and back feet of both sprinters was calculated by measuring the area under their respective force-time curves and converting the units to 'pound-seconds' (Table V). A 'weighing technique' which measured relative weight of the cut-out areas was used to determine these values.

TABLE V

Impulse Recorded from Front and Back Feet

A. Boundaries of Force-Time Curve Established
through Beckman Recording

	Front Foot (lb.sec)	Back Foot (lb.sec)	Total (lb.sec)
Experienced Sprinter	30.31 (58%)	21.84 (42%)	52.15
Inexperienced Sprinter	31.30 (60%)	20.36 (40%)	51.66

B. Boundaries of Force-Time Curve Established
Through Honeywell Integrator

	Front Foot (lb.sec)	Back Foot (lb.sec)	Total (lb.sec)
Experienced Sprinter	28.71 (58%)	20.93 (42%)	49.64
Inexperienced Sprinter	30.13 (60%)	19.66 (40%)	49.79

Maximum Force and Acceleration

The maximum acceleration of the body's center of gravity as well as the maximum force recorded by the front and back feet of both sprinters was calculated (Table VI).

TABLE VI

Maximum Force Recordings

	Maximum Force Front Foot (lbs)	Maximum Force Back Foot (lbs)	Center of Gravity Maximum Acceleration (ft/sec ²)
Experienced Sprinter	171	195.7	63.4
Inexperienced Sprinter	152	188	55.0

Horizontal movement time. The time which elapsed between the signal (i.e. sound of gun) and the first horizontal recording of force was found to be 0.12 and 0.14 seconds respectively for the experienced and inexperienced sprinters. The time over which the impulse on the starting blocks lasted was found to be 0.34 and 0.36 seconds respectively for the experienced and inexperienced sprinters.

Film Analyses

Center of gravity displacement. It was observed from film analyses that the experienced sprinter's center of gravity moved 3.16 feet during the start while the inexperienced sprinter's center of gravity moved 3.04 feet. However, if one measured this change in distance from the starting blocks, it was found that the experienced sprinter had a full inch advantage to begin with. Thus he was

approximately 2.2 inches farther ahead if one just considered horizontal displacement of the body's center of gravity during the first stride.

It is of interest to note that the actual length of the first stride, as measured from the footplate of the front starting block to the point where the right foot contacted the ground, was found to be 3.84 and 3.81 feet respectively for the experienced and inexperienced sprinters.

Horizontal displacement time. The first discernible movement (either horizontal or vertical) was found to occur in the thigh of the back leg for both sprinters. This was found to occur at frame #7 for the experienced sprinter and at frame #8 for the inexperienced sprinter.

Discussion

Comparison of the Results from Cinematographical Analyses and Force Recordings

Impulse. It was found that the values for the total impulse delivered to the body during the start, as calculated by film analyses, was in close agreement with the values obtained from the force recordings (Table II, Table III). However, if one were to examine the sprint start subjectively, one would expect the impulse as recorded by the force-blocks to be slightly greater than that calculated by film analysis. This would be due to the fingers which are supplying a resistive horizontal force in the initial stages of the start in order to compensate for the horizontal force applied

against the force-blocks by the feet while the sprinter is in his 'set' position (This is evident from the change in the baseline before and after his start). Therefore the initial impulse as recorded by the blocks would be working against the retarding force of the fingers and thus would not represent the net impulse delivered to the body at that stage in the start.

In the calculation from the force recordings of the effective impulse delivered to the body, the retarding action of the finger tips was, in all probability, over compensated for. The true impulse would be better approximated if the base line, which occurred after the start, was used as a boundary under the force-time curve instead of the baseline which occurred before the start (a result of the force from the finger tips). This was due to the fact that the finger tips leave the ground early in the start and thus cannot be supplying a resistive force to the body during the later stages of the start.

One of the possible reasons why the impulse recorded by the force-blocks was not abnormally low, when measured as above, would be due to the mechanical restoring time of the force blocks being of significant magnitude to cause a greater impulse to be recorded than was actually present.

The total impulse delivered to the body over the time period between two consecutive frames of film, as measured by cinematographical analysis, was found to fluctuate quite noticeably around the values obtained from the Honeywell

Integrator (Table II, Table III). The reason for the fluctuation would most likely be due to the fact that the film analysis was assuming that the body was a true hinged link system, which, of course, was not exactly the case. Nevertheless, the average value over a number of frames should approach the expected value since an under estimation of impulse in one frame would lead to an over estimation of impulse in the following frame and thus the errors would tend to minimize one another. As can be seen from Table II and Table III, this was indeed what occurred.

In calculating the impulse by means of film analysis, an error occurred which was inherent to this method of calculation. This error was a result of the assumption that the acceleration was constant during the time interval between successive frames, which of course was not the case.

The impulse delivered to each segment during any phase of the start was calculated as well as the total net impulse which a segment received over the entire start. Unfortunately no definite conclusions could be drawn from this information concerning the problem of establishing which segments were responsible for producing the total impulse. This was due to the fact that any segment which was accelerated would necessarily have an impulse associated with it no matter if it was active or passive in the resulting action.

Maximum force and acceleration. The maximum force of the back foot was found to be 14.4% greater than the maximum force of the front foot for the experienced sprinter. For the inexperienced sprinter, the difference was found to be 23.7%. Lanier (1968) obtained a value of approximately 30% for a similar measurement from the recordings of his sprinter. The true measure of the sprinter's effectiveness though, was the combined force exerted on the blocks at these stages of the start. It would seem from observing both sprinter's force-time curve, that a greater effort to produce a larger force from the front foot earlier in the start would be most desirable since this was the ideal time maximum acceleration should occur.

Horizontal movement time. The horizontal movement time of .12 and .14 seconds was a bit slower than the .10 second value which was reported by Lanier (1968), but was in close agreement with .12 seconds reported by Henry (1952). The duration of the impulse for the experienced and inexperienced sprinter was found to be .34 and .36 seconds respectively. Henry (1952) reported a value of .37 seconds while Lanier (1968) reported a value of .32 seconds. Thus the obtained values would seem to be in order and the variation could be attributed to individual differences.

Force-time pattern. The force time pattern recorded for both sprinters was similar to those obtained by Lanier (1968) and Payne (1971). The back foot's force-time recording

was symmetrical while that of the front foot showed two peaks with the first being quite a bit lower than the second.

It was of interest to note that the termination of impulse on the blocks, as indicated by the Honeywell Integrator, occurred at a point on the force-time curve which was approximately midway between the maximum force of the front foot and the mechanical zero baseline. Thus it appeared that although the front foot had not left the blocks, it was not applying any force to the block at this stage. The same was most likely true for the back foot although it was probably not as appreciable since it was quickly removed from the block during the early stages of the start. This point seems to have been neglected in previous reports of force-time analysis.

In general, a close relationship was found between the results of the force-time recordings and cinematography. Murray (1967) and Roy, as cited by Roberts (1971), found this to also be the case.

A Subjective Analysis of the Sprint Start

If one subjectively analyses the sprint start, one would expect almost the entire impulse to be generated by the legs with the arm action being used almost entirely for stabilization purposes since the total combined action of the arms would effectively cancel out over a complete arm cycle. However, the arms have a most important early function in a good start in that they can apply early force

to the block (and thus to the body) while still allowing the legs to be kept in a flexed position. This means that the legs will be able to apply a force to the body for a longer period of time. Thus the total resulting acceleration from the blocks will be greater than if the legs acted alone.

It should be understood that the basic idea of a good start is for the sprinter to accelerate to his/her optimum velocity as quickly as possible. Thus if two sprinters are of equal mass and both record equal values of impulse, the impulse, which is generated over the shorter period of time will be the superior effort. This means that if one is to interpret a force-time recording for any event whose outcome is time dependent (or in other words, the distance is constant), one should not just observe the magnitude of the impulse but should also examine the time duration of the impulse.

When the two force curves of both sprinters were examined, it was quite evident that the experienced sprinter's force curve was superior, for not only was it executed 0.02 seconds sooner but also the time of execution was 0.02 seconds less than that of the inexperienced sprinter. It should be remembered at this point that the total impulse for both sprinters was approximately the same but that the inexperienced sprinter's mass was 1.09 times that of the experienced sprinter. Thus, not only was the final velocity of the experienced sprinter off the blocks greater, but it was

achieved earlier than the final starting velocity of the inexperienced sprinter and thus would enable him to cover a given distance in a shorter period of time.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to assess the contribution of each major body segment to the sprint start, and to compare the results of two cinematographical analyses with their respective results from the force-blocks.

Two volunteer male subjects were used. One was an experienced sprinter from the Edmonton Olympic track team, and the other was a student from the University of Alberta who had little previous experience in starting from the blocks. The toe-boards on the starting block were spaced fourteen inches apart which was the preferred spacing of the experienced sprinter. Five starts were performed by both sprinters. The fourth start of both sprinters was chosen to be studied in greater detail due to the similarity of the pattern of their respective force-time curves.

All the starts were filmed at approximately 64 frames per second. From the film analysis, the impulse received by each segment was calculated between successive frames and this impulse was compared to the impulse on the force blocks as calculated by the Honeywell Integrator.

A close sychronization between body positions and their location on the force-time curves was attained by

using an accurate interval timer.

Conclusions

(1) From the results obtained it would appear that static calibration of force-blocks (or force plate) can be justified in the calculation of basic parameters of a dynamic action such as a sprint start.

(2) The results of the technique used to attain synchronization between body positions and force recordings would indicate that this method was precise and accurate.

(3) Although the impulse received by a segment(s) was calculated, no conclusions can be drawn with regard to the magnitude of the impulse which a particular segment generates during a sprint start.

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APPENDIX A

SUBJECT MEASUREMENTS

DATA FROM SUBJECT MEASUREMENTS

Subject A

Name: David Powell

Quality of starter: top highschool sprint starter

Total height: 69.25 inches

Total weight: 143.50 pounds

Age: 17 years

Segment	Length (in.)	Center* of Gravity (in.)	Weight (lbs.)
Head, neck and trunk	34.00	13.46	75.78
Arm	11.25	4.90	2.57
Forearm	11.50	4.95	
Hand	5.50	2.78	
Forearm and Hand	17.00	7.47	4.46
Upper leg	16.25	7.04	17.40
Lower leg	18.00	7.79	
Lower leg and foot (flexed)	21.00	10.67	9.43
Lower leg and foot (extended)	26.75	10.79	9.43

The distance from the distal end of the lower leg to the vertical plane of the center of gravity of his foot in both the extended and flexed positions was 2 and 2.5 inches respectively.

*Centers of gravity are measured from the proximal end of the segment(s).

DATA FROM SUBJECT MEASUREMENTS

Subject B

Name: Joseph Rabel

Quality of starter: inexperienced sprint starter

Total height: 68.75 inches

Total weight: 156.50 pounds

Age: 26 years

Segment	Length (in.)	Center of gravity (in.)	Weight (lbs.)
Head, neck and trunk	32.50	12.87	82.76
Arm	11.25	4.90	3.47
Forearm	11.25	4.84	
Hand	6.00	3.04	
Forearm and hand	17.25	7.42	5.73
Upper leg	16.00	6.93	18.41
Lower leg	17.50	7.58	
Lower leg and foot (flexed)	19.50	10.39	9.26
Lower leg and foot (extended)	26.50	10.57	9.26

The distance from the distal end of the lower leg to the vertical plane of the center of gravity of his foot in both the extended and flexed positions was 2 and 2.75 inches respectively.

DATA FROM REACTION BOARD MEASUREMENTS

Subject A

Δ Position [*] (Fig. 8)	Scale Reading Initially (S)	Second Scale Reading (S')	(S-S')
A $\rightarrow$ B	99.80	100.70	.90
A $\rightarrow$ C	99.80	102.40	2.60
A $\rightarrow$ F	99.80	107.25	7.45
D $\rightarrow$ E	113.60	116.35	2.75

Subject B

Δ Position (Fig. 8)	Scale Reading Initially (S)	Second Scale Reading (S')	(S-S')
A $\rightarrow$ B	108.00	109.15	1.15
A $\rightarrow$ C	108.00	111.35	3.35
A $\rightarrow$ F	108.00	115.45	7.45
D $\rightarrow$ E	123.00	125.60	2.60

* Refer to Figure 8 for description of positions.

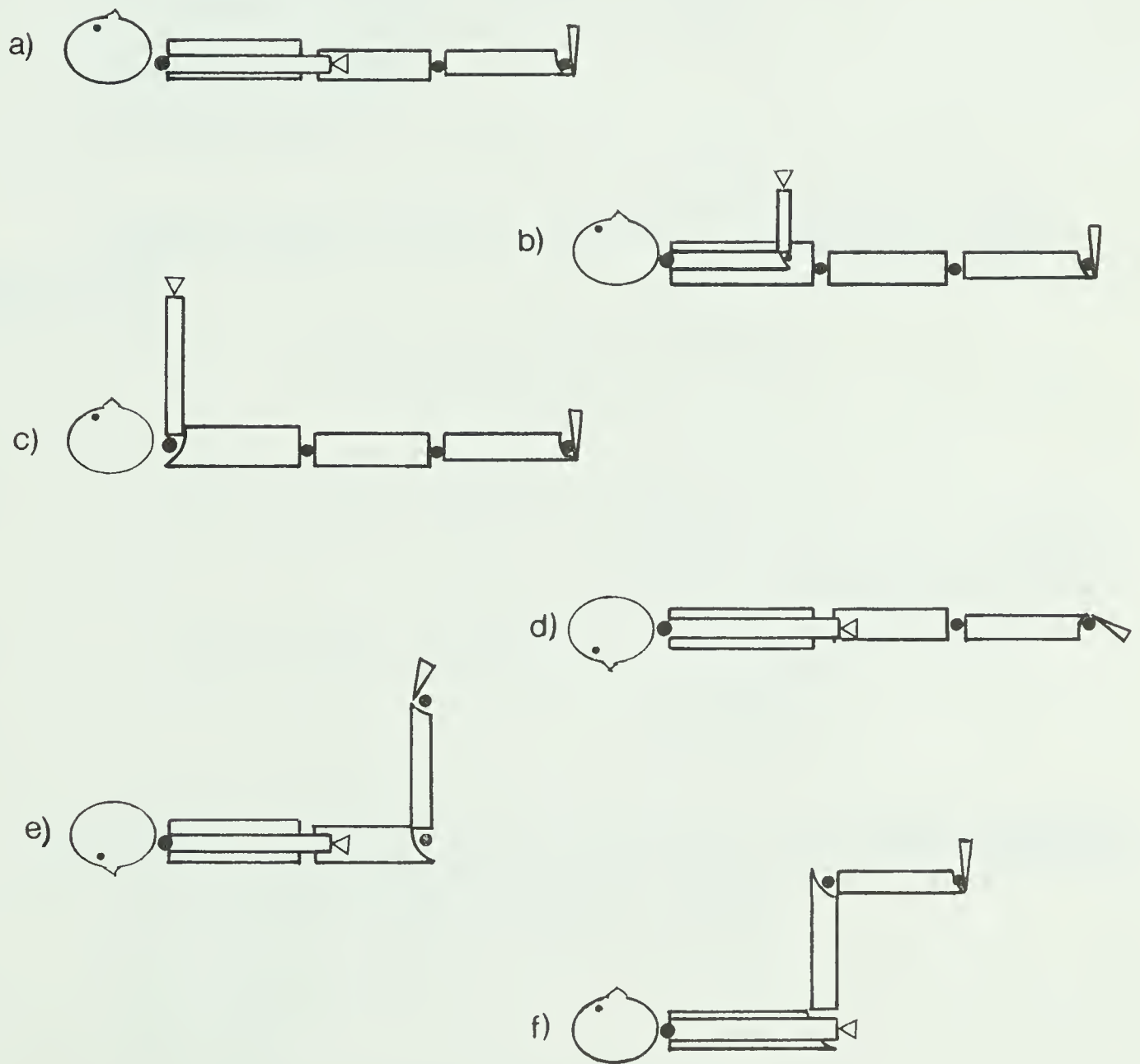


FIG. 8: POSITIONS ASSUMED FOR THE MEASUREMENT OF
SEGMENT MASSES

A SAMPLE CALCULATION OF SEGMENT WEIGHTS
USING THE REACTION BOARD TECHNIQUE

Subject A

I Center of gravity* for lower leg and foot combined.

$R = \text{weight of lower leg} + \text{weight of foot}$

$R = 143.5 \times .0470 + 143.5 \times .0145$

$R = 6.74 + 2.08$

$R = 8.82 \text{ lbs.}$

Taking moments about the center of gravity of the lower leg:

$$8.82 X = 2.08 (10.21 + 2)$$

$$X = 2.88$$

$$\therefore C \text{ of } g \text{ (foot flexed)} = 2.88 + 7.79$$

$$= 10.67 \text{ in. (distal to knee)}$$

$$C \text{ of } g \text{ (foot extended)} = \frac{2.08 \times 12.71}{8.82} + 7.79$$

$$= 10.79 \text{ in.}$$

II Center of gravity for the forearm and hand combined.

$$R = 143.5 \times .0160 + 143.5 \times .0060$$

$$R = 2.30 + .86$$

$$R = 3.16$$

$$3.16 X = .86 (6.55 + 2.78)$$

$$X = 2.52 \text{ in.}$$

*The center of gravity locations are established through the use of Dempster's values, as cited by Williams and Lissner (1962:132)

$$\begin{aligned} \therefore C \text{ of } b &= 2.52 + 4.95 \\ &= 7.47 \text{ in. (distal to elbow)} \end{aligned}$$

III In order to obtain a measure of the weight of a segment(s) from the reaction board technique, the following formula from Williams and Lissner (1962:138) was used:

$$W = \frac{L (S - S')}{\Delta X}$$

where w = weight of segment

L = distance between two
supports on reaction
board

$S - S'$ = change in scale reading

ΔX = horizontal change in the
position of the segment's
center of gravity

Weight of one forearm and hand

$$W = \frac{L (S - S')}{\Delta X}$$

$$W = \frac{1}{2} \frac{74 (100.70 - 99.80)}{7.47}$$

$$W = 4.46 \text{ lbs.}$$

IV Weight of arm

$$W = \frac{L (S - S')}{\Delta X}$$

Change in scale reading attributed to both forearms and hands.

$$4.46 \times 2 = \frac{74 (y)}{11.25 + 7.47}$$

$$y = 2.26$$

$$\therefore W = 2.57 \text{ lbs.}$$

V Weight of lower leg and foot.

$$W = \frac{1}{2} \frac{74 (116.35 - 113.60)}{10.79}$$

$$W = 9.43 \text{ lbs.}$$

VI Weight of upper leg

$$W = \frac{L (S - S')}{\Delta X}$$

Change in scale reading attributed to both lower legs and feet.

$$9.43 \times 2 = \frac{74 (y)}{16.25}$$

$$y = 4.14$$

$$\therefore W = \frac{1}{2} \frac{74 [(107.25 - 99.80) - 4.14]}{7.04}$$

$$W = 17.40 \text{ lbs.}$$

APPENDIX B

CALIBRATION AND PREADJUSTMENTS

CALIBRATION AND PREADJUSTMENT PROCEDURES

Preadjustments. The Beckman RS Dynograph recorder was preadjusted according to the procedure outlined in the Beckman instruction manual (1968:3).

The Accudata 113 Bridge Amplifier of the Honeywell Medical System was used strictly as a d.c. amplifier. It was adjusted for a .2V full scale deflection according to the procedure outlined in the Honeywell instruction manual (1968:7:Section III).

The Honeywell Physiological Integrator was preadjusted according to the procedure outlined for the area summator of the Honeywell physiological integrator instruction manual (1968:11:Section II).

Calibration. The force blocks were adjusted by means of the two potentiometers in the power supply box for equal sensitivity. The sensitivity was set to give a .075 V output for every ten pounds of force applied by either foot. The pen deflection of the Beckman recorder was set for a sensitivity which, when coupled with the force blocks and the other recording instruments, gave a one millimeter deflection for every 9.5 pounds of force.

The Honeywell Physiological Integrator was calibrated to produce a one centimeter deflection for every 10 lb. sec of impulse.

In order to prevent too high a voltage from being passed into the d.c. amplifier, a potentiometer was used

which reduced the input voltage to the d.c. amplifier by a factor of .058.

It was found that the filming speed for the experienced sprinter was such that the time interval between frames was .0173 seconds. For the inexperienced sprinter, the time interval worked out to be .0176 seconds.

CALIBRATION OF THE FORCE BLOCKS
(FINAL READINGS)

Trial	LEFT BLOCK		RIGHT BLOCK	
	Voltage Without Load	Voltage With Load (19.80 lbs)	Voltage Without Load	Voltage With Load (19.80 lbs)
1	.228	.376	.273	.422
2	.230	.378	.278	.425
3	.229	.381	.274	.425
4	.226	.378	.276	.426
5	.228	.375	.278	.424
6	.231	.377	.276	.425
7	.225	.373	.277	.426
8	.230	.379	.275	.425
9	.226	.375	.274	.424
10	.231	.380	.275	.424
	<u>.2286</u>	<u>.3772</u>	<u>.2756</u>	<u>.4246</u>
	$\bar{x}$.2286	$\bar{x}$.3772	$\bar{x}$.2756	$\bar{x}$.4246

For left block -

$$19.80 \text{ lbs} \rightarrow (.3772 - .2286) \text{ Volts}$$

$$10 \text{ lbs} \rightarrow \frac{10 (.3772 - .2286)}{19.80} \text{ Volts}$$

$$10 \text{ lbs} \rightarrow .075 \text{ Volts}$$

For right block -

$$19.80 \text{ lbs} \rightarrow (.4246 - .2756) \text{ Volts}$$

$$10 \text{ lbs} \rightarrow \frac{10 (.4246 - .2756)}{19.80} \text{ Volts}$$

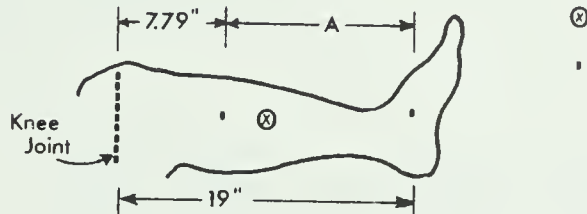
$$10 \text{ lbs} \rightarrow .075 \text{ Volts}$$

APPENDIX C
CALCULATION OF IMPULSE

CALCULATION OF IMPULSE

The 'Center of Gravity' program developed by Miller (1970) was used to determine the positions of the center of gravity for the segments, or combination of segments, desired. By leaving out the finger tip coordinates from the computer input data, a combined center of gravity plot for the forearm and hand was obtained. In order to determine the combined center of gravity plot for the lower leg and foot, the following procedure was followed:

Calculation of Center of Gravity for Lower Leg and Foot Combined



$$X = \frac{\text{Distance of combined center of gravity from center of gravity of foot}}{\text{Distance between centers of gravity of lower leg and foot}}$$

$$X = \frac{\text{C. of b. combined}}{A}$$

$$X = \frac{(19 - 10.67)}{(19 - 7.79)} = .74$$

Therefore .74A is the distance that the combined center of gravity is from the center of gravity of the foot. Thus, .74A + 'X' coordinate of foot's center of gravity gives the horizontal position of the center of gravity of the combined lower leg and foot.

From the horizontal distance travelled between every two frames of film, the average velocity over this time interval was obtained. For convenience, the average velocity was thought of as occurring midway between the two frames.

In reality this would not be true due to the fact that acceleration was not constant. The impulse was then calculated between the mid-points of each pair of successive frames. That is:

$$\int_{t_1}^{t_2} F dt = M (V_2 - V_1)$$

where: M = mass of segment

V_2 = Velocity at second frame

V_1 = Velocity at first frame

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